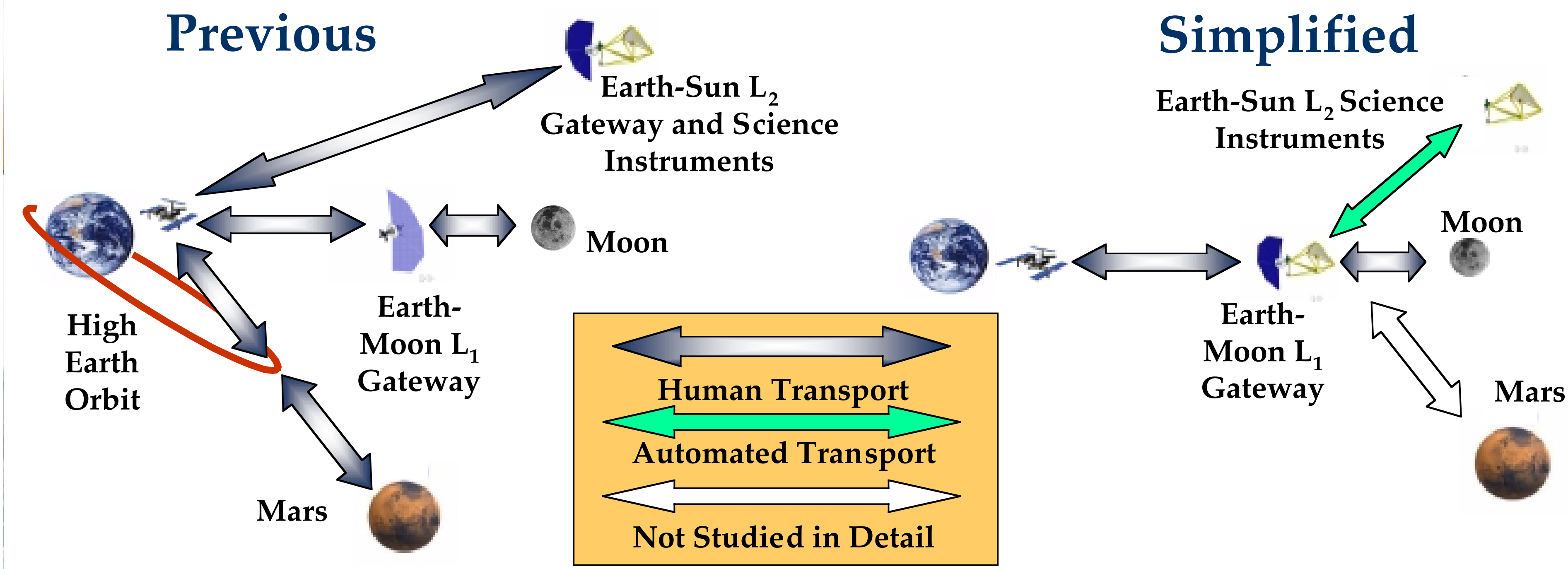
Earth's Neighborhood
Simplified Infrastructure



	Previous	Simplified
Gateways	2 –3 (depends upon Earth-Sun L_1 operations requirement)	1
Human Transportation Systems	3 (depends upon requirements impacts on design)	1
Maximum Out and Back Transit Time	40 days	8 days

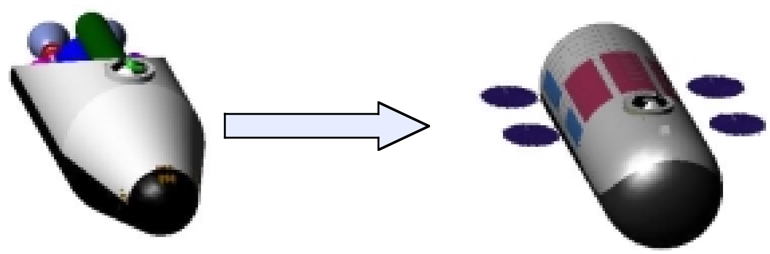
Reports Available

Unique Orbital Dynamics

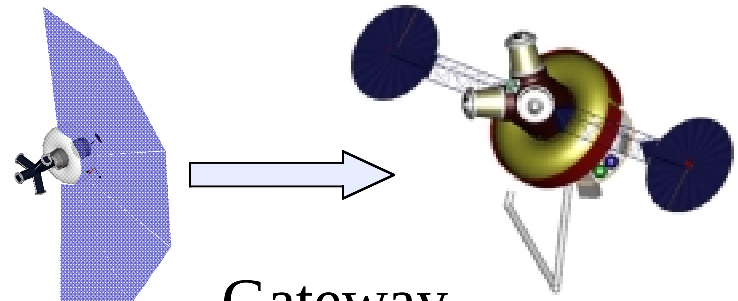
- Orbital Dynamics in Earth-Moon System leads to unique capabilities
  - *Extremely* Low-Energy Transfer from Earth-Moon L_1 to Solar Lagrange Points and Return
  - Allows human operations at Earth-Moon L_1 (four day transfer from/to LEO vs two weeks to/from Earth-Sun Lagrange Points)
  - Allows automated deployment/retrieval of science instruments to/from Earth-Sun Lagrange Points from Earth-Moon L_1 (3-4 month transfer)

Start and End Point Locations	Delta V (Low Energy Transfer Method)	Delta V (Traditional Hohmann Transfer Method)
LEO to Earth-Moon L_1	N/A	3900 m/sec, 3 days
LEO to Earth-Sun L_2	N/A	3800 m/sec, 20 days
Earth-Moon L_1 to Earth-Sun L_2	14 m/sec, ~ 100 days	140-710 m/s

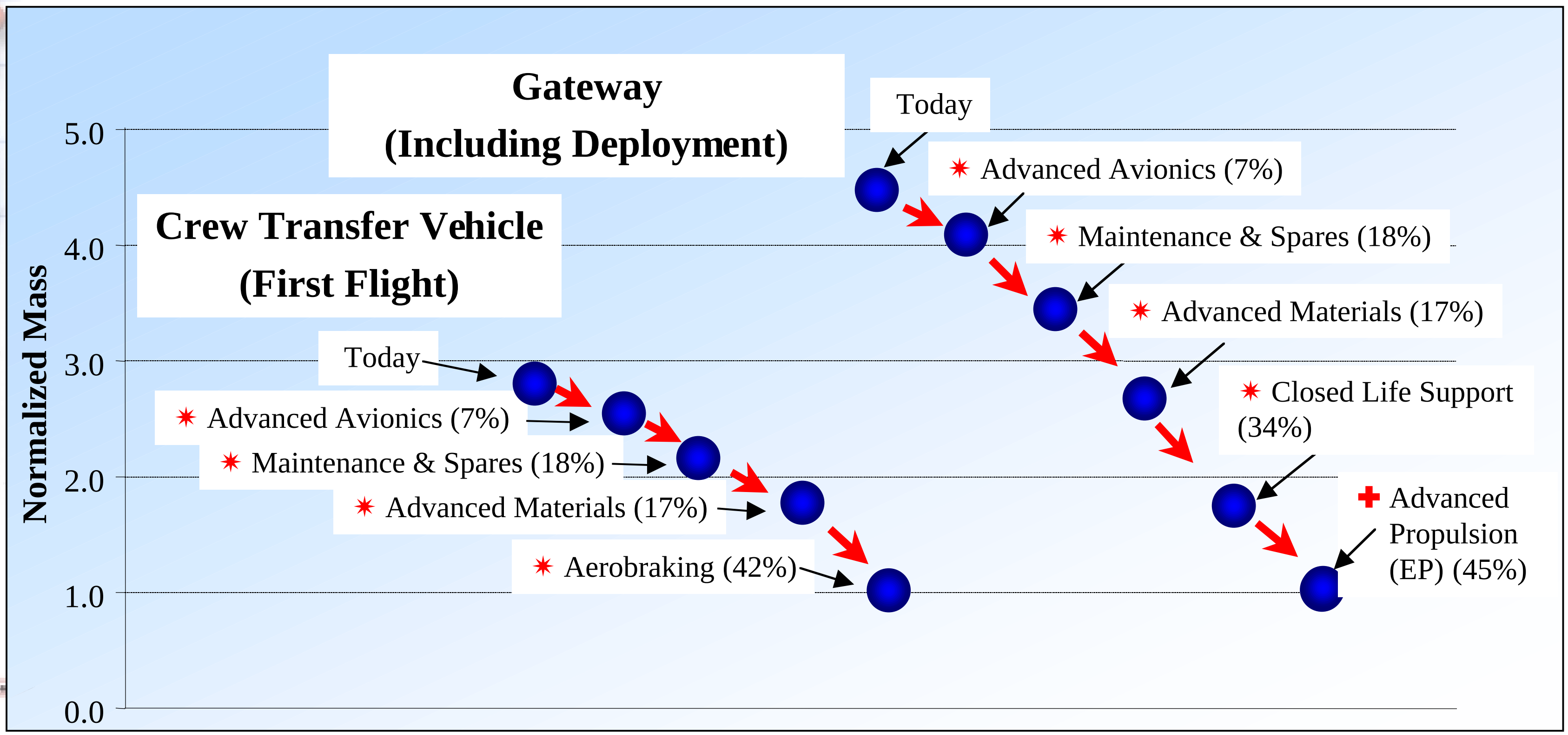
Evolution in Vehicle Designs



Crew Transfer Vehicle



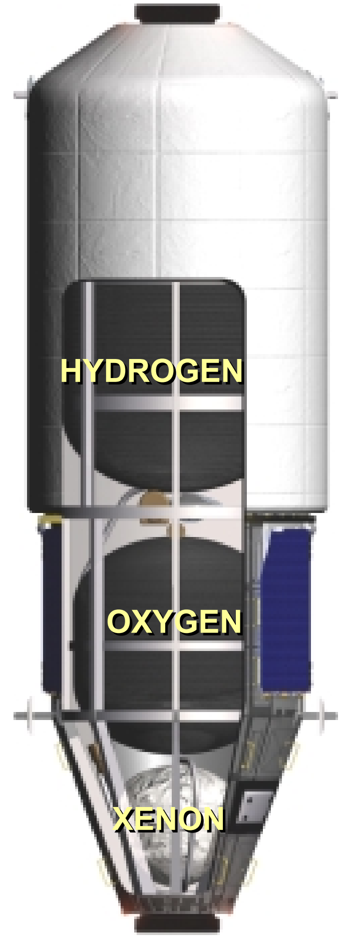
Gateway



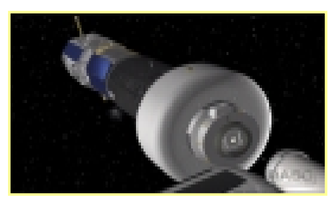
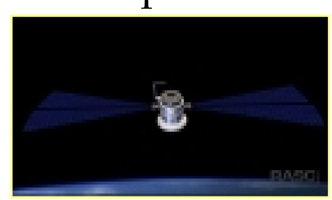
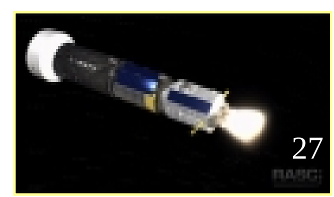
Hybrid Propellant Module (HPM)

- **Objectives**
  - Develop robust and cost effective concepts in support of future space commercialization and exploration missions assuming inexpensive launch of propellant and logistics payloads

- **Commercial Opportunities**
  - A reusable in-space transportation architecture composed of modular fuel depots, chemical/solar electric stages and crew transportation elements



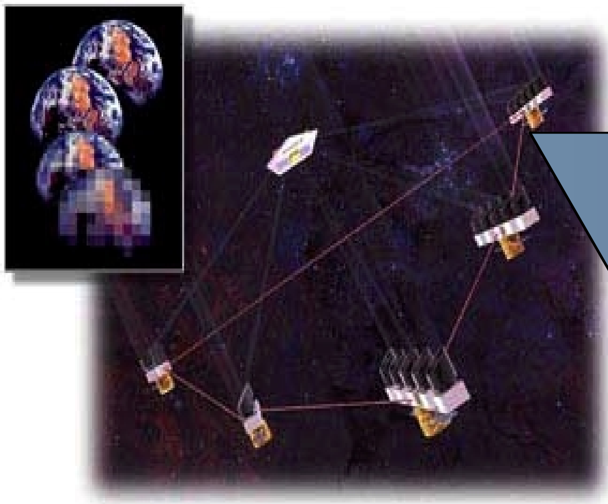
Infrastructure Elements:

Lunar Gateway	Space Station	Crew Transfer Vehicle	Solar Electric Propulsion	Chemical Transfer Module
				

Overview
FY01 Focus Areas

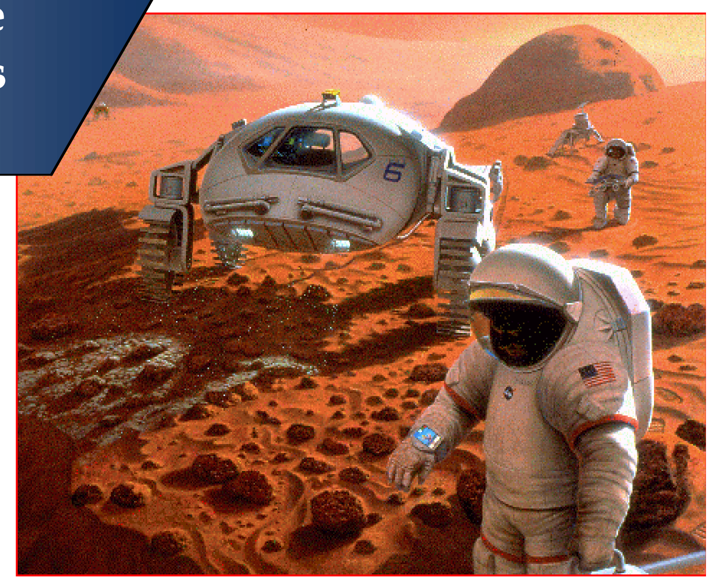
- **Prioritize investments to achieve Agency goals**
- **Improve understanding of the Earth's Neighborhood**
  - Refine concepts and science needs
- **Improve definition of the robotic/human partnership in space**
  - Capture the state-of-the-art for future robotics
  - Quantify and compare robotic/human performance in projected operations
  - Increase understanding of critical Bioastronautics issues
- **Advance Technology for Human/Robotic Exploration and Development of Space (THREADS)**
  - Discover innovative concepts and technology
  - Show progress in key technology areas
- **Expand leveraging activities**
  - Active investments from; NIAC, RASC, SBIR, SSP
  - DoD - opportunities through Technology Area Review and Assessment (TARA), Advanced Concept Technology Demonstrations (ACTD), etc.
  - Education; Steckler Trust

Optimizing the Human/Robotic Equation



- Technology Projections
- Experience and Lessons Learned
- Misson Performance Assessments

Optimal Human and Robotic Combinations



Example Science Activities

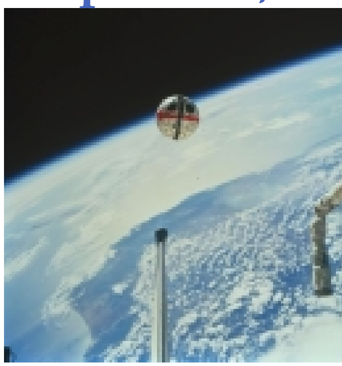
Creating science instruments and observing platforms to search for life sustaining planets

Search for evidence of life on planetary surfaces

Human/Robotic Partnership

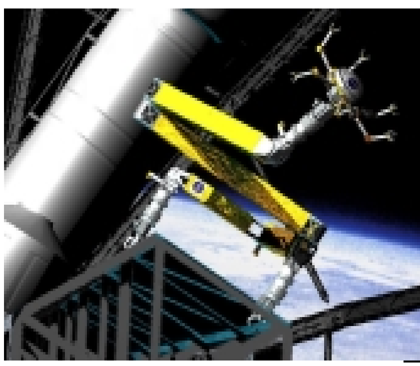
Robotics State-of-the-Art and Technology

In-Space Assembly, Inspection, and Maintenance

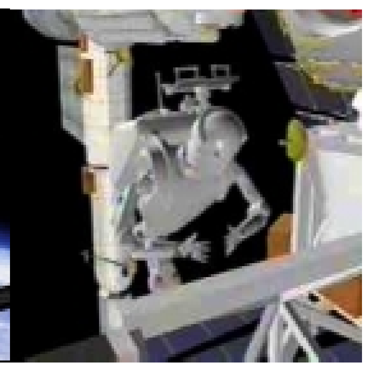


Inspection

Maintenance

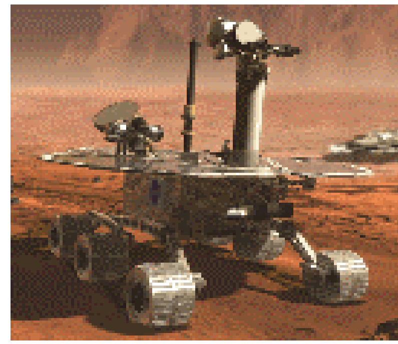


Assembly of Large Structures

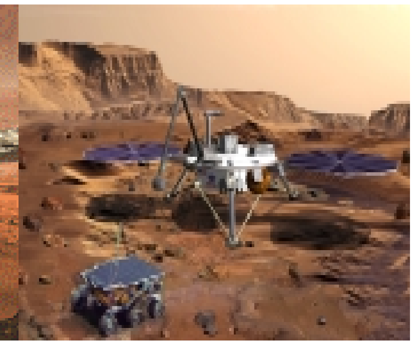


Troubleshoot and Repair

Planetary Surface Exploration

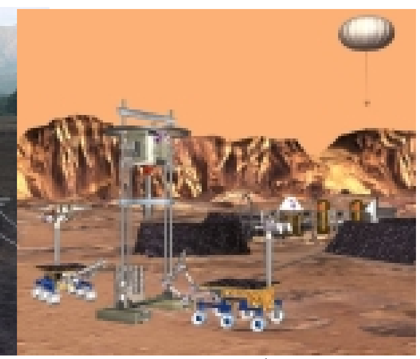


Long Range Reconnaissance



In Depth Site Survey

Joint Human/ Robotic



Sample Acquisition and Analysis

Report Available - Robotics State of the Art

Human/Robotic Partnership

Robotics State-of-the-Art Technology Projections

Science Objectives → Desired Measurements → Mission Concepts → Required Capabilities → Robotics Technology

Return all data

Return selected data

Select targets

Characterize site

Recognize unforeseen scientific opportunities

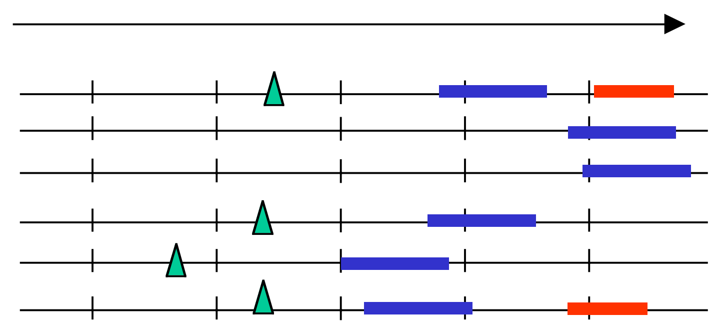
Breakthroughs

On-board science perception functions and capabilities

Increasing time and capability

Planetary Exploration Example

- Mobility
- Autonomy
- Mechanism
- Science Operations
- Science Perception, Planning and Execution
- Sample handling and manipulation



Near term capability projection

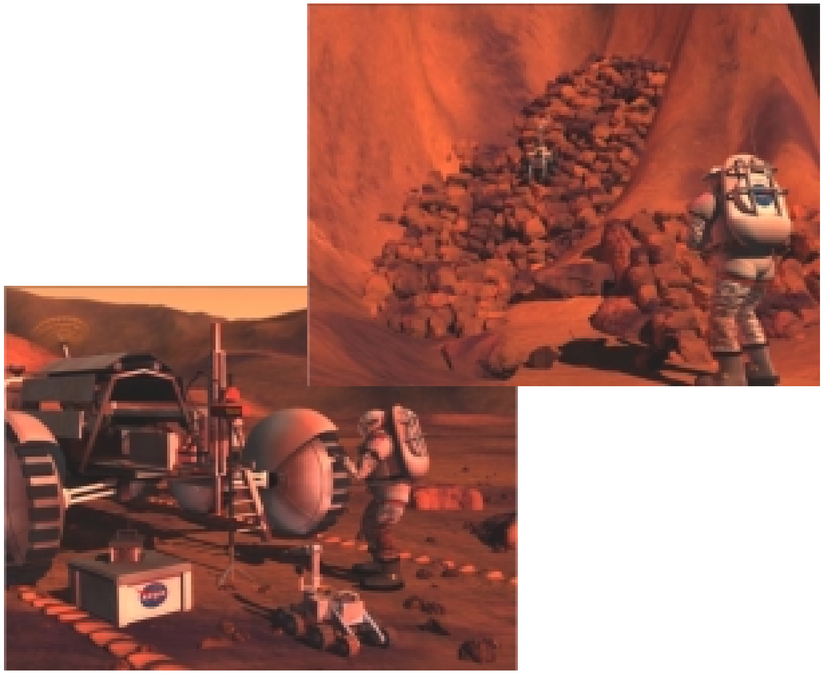
Long term capability projection

Existing space robotics capability

Human/Robotic Partnership

Humans On-Site Enable New Science

- **Understand human "on-site" exploration and required technology development to optimize human performance for science driven missions**
- **Workshops**
  - Science and Human Exploration of Mars - January 11-12, 2001
  - Human Enabled Science - May 1-2, 2001



- **Results:**
  - Humans bring additional capabilities: (examples)
    - In-situ judgment, rapid decision making, rapid mobility, serendipity, recognition, redesign adaptability, etc
  - Best science task(s) suited for humans: (examples)
    - In situ analysis and sample handling/preparation, in situ field observations and sample collection/selection, complex instrument deployment including deep drilling, adaptable redesign of science hypotheses, etc

Report Available - Workshop on Science and the Exploration of Mars

Human/Robotic Partnership
Antarctic Workshop Results

- **Several expeditions to the Antarctic after WW II approached the duration and isolation of proposed Mars surface missions**
  - Two years total duration on the ice
  - Over 1000 miles traverse distances

- **Four experienced Antarctic explorers invited:**
  - Dr. Charles Bentley, University of Wisconsin
    - Two consecutive seasons in Antarctica during IGY; led 1000+ mile traverse
  - Dr. Richard Cameron, Webster University
    - One season in Antarctica during IGY; NSF representative at South Pole Station (1975-1985)
  - Dr. Mario Giovinetto, NASA/GSFC
    - Two consecutive seasons in Antarctica during IGY; over 2000 miles of over-snow traverse work
  - Dr. Charles Swithinbank, Scott Polar Research Institute
    - Two consecutive seasons in Antarctica as part of Norwegian-British-Swedish team (1949-1952); participated in multi-hundred mile traverses during this expedition; almost 40 polar expeditions during career (appoximately 10 Arctic, 30 Antarctic)
- **Increased understanding of crew and operational considerations with additional information gained relative to hardware and systems**
- **Lessons learned include simplicity, risk tolerance, independence**

Report Available - Antarctic Exploration Parallels

Human-Robot Performance Assessment Process

Decompose Scenario

Primitives: Discover rocks, carry rocks, traverse, recover from mishaps, etc.

Quantify Primitive Parameters

Parameters: EVA duration, traverse distance, rock abundance, etc.

Determine Aptitudes

Scores/primitive for each HR system: data base, thought experiments, models, etc.

Compute Composite Scores

Multi-primitive scores: e. g., probability of success

System Options

- 2 Astronauts walk
- 2 Rover scouts
- 2 Astronauts ride transport vehicle
- Robot assists 2 walking astronauts
- 2 Autonomous rovers controlled from Earth

Preliminary Results

Human-Robot Surface System Options	Mobile Resources Required	Performance/Benefits of System Options
2 EVA Astronauts Walk	Moderate mass and power	Limited Range; at-the-site expert geology
2 EVA Astronauts Ride Rover	Higher mass and power	Extended range; at-the-site expert geology
2 Rover Scouts Controlled from Mars Base	Low mass and power	Expert geology tele-presence; extended range
Robot Assists 2 EVA Astronauts	Moderate mass and power	Coordinate area coverage; load carry aid
2 Robots Controlled from Earth	Lowest mass and power	Low effective traverse rate; high autonomy

Reports Available - Performance Assessment Methodology Workshop, Assembly of Large Telescopes, Field Geology and Sample Collection

Human/Robotic Partnership
Summary Perspective

- **Humans and robots have collaborated in every NASA mission**
  - Difference between missions is the physical interfaces and proximity of humans
- **Hubble Space Telescope and Apollo demonstrated significant increase in rate of science return through involvement of humans at local science site**
- **Humans and robots represent different tools for accomplishing different jobs**
  - Humans have capabilities not yet attained by robotics
  - Robots more efficient for repetitive tasks and expendable for high risk tasks
- **Understanding benefits and risks of human and robotic capabilities is complex and evolving**

NEXT objective is to optimize integration of humans and machines to maximize overall capabilities for effective scientific discovery

Bioastronautics Research

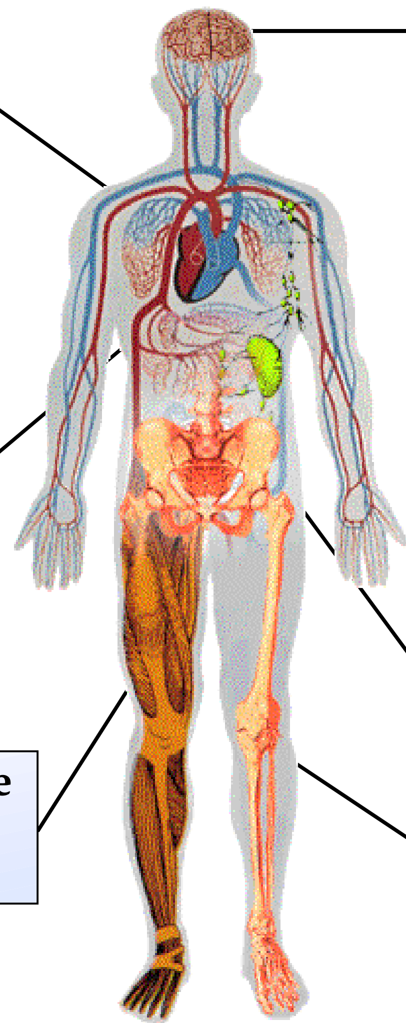
Contributions to NEXT Goals

Variation in crew radiation limits and risk relative to age and sex

Red blood cell loss due to hormone decrease

Ground therapies for fainting are effective for similar space flight symptoms

Resistive exercise may be effective remedy for muscle/strength decrease



"Hardwired" mental model of gravity conflicts with hand/eye coordination of motor tasks in zero-G (ball catching)

Bright light therapy is an effective approach to shifting circadian rhythms

Promethazine is an effective drug for space motion sickness in most crew

Resistive exercise and drugs promise to address bone losses (1% per month)

8 countermeasures operational, 7 undergoing validation, > 100 basic research tasks ongoing

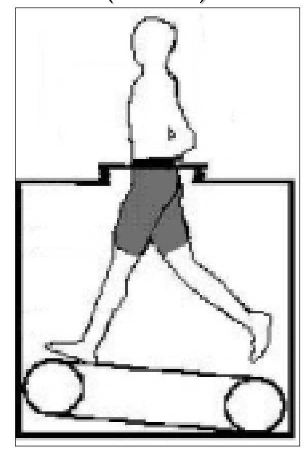
Human Planning Guidelines/Constraints

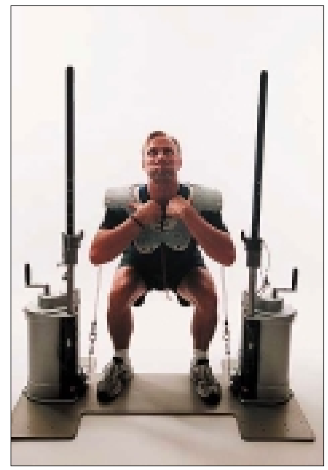
Enabling Trades

- **Radiation studies (reduce uncertainties in risk values, foster early integrated design practices)**
- **Artificial gravity countermeasures (centrifuge/exercise vs exercise)**
- **Reduced cabin pressure (trade mass vs avionics cooling and material flammability – push for lower than 10 psi and higher than 30% O_2)**
- **Closed loop life support CO_2 removal (enzyme membranes, amines, swing beds, etc)**
- **Number of crew for remote exploration (minimize impacts/risk while maximizing productivity)**
- **Anthropometrics (limited size range minimizes costs and vehicle/mission design impacts)**

Space Cycle™

Exercise in Lower Body Negative Pressure (LBNP)





ISS Resistive Exercise Device

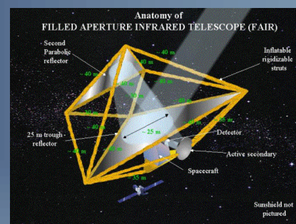
Self-Generated LBNP

Human-powered centrifuge

Report Available - Human Planning Guidelines and Capabilities

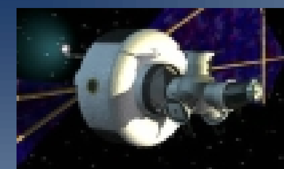
Human as Subsystem

Mission/Science



- Transit Time
- Surface Power
- Number of Crew
- Human/Robotic Integration

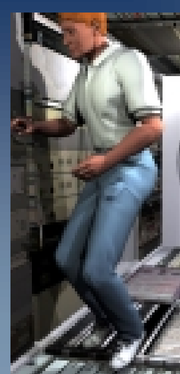
Technology/Vehicle



- Shielding Materials
- Artificial Gravity
- Anthropomorphic
- Cabin Pressure/ECLSS

NEXT Strengthening

Humans



- Radiation Health
- Physiology
- Psychological Support
- Training/Performance

Identify and integrate the points of intersection between the human as a subsystem, mission/science applications and the implementation technologies

Overview
FY01 Focus Areas

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  - DoD - opportunities through Technology Area Review and Assessment (TARA), Advanced Concept Technology Demonstrations (ACTD), etc.
  - Education; Steckler Trust

THREADS
Overview

- **FY 2001 update of the THREADS Strategic Research & Technology (R&T) road maps will be limited to relatively modest changes and/or improvements on the product from FY 2000**
- **Key ground rules and assumptions**
  - No major changes in requirements
  - No major changes in the THREADS work breakdown structure (WBS)
  - A one-year adjustment in schedule assumptions regarding previously planned “cycles of innovation”
  - The update of the THREADS road maps will be an iterative process, continuing into the Fall
- **Major planned road map updates**
  - Revision of milestones at all levels, consistent with one-year slip
  - Identification and documentation of key technology metrics
  - Creation of schedule road maps at various levels in the Work Breakdown Structure
- **Other Major Products of the THREADS team for 2001**
  - Applications Assessment

THREADS

Progressive Exploration Capabilities

Downselect points

Earth's Neighborhood Capability

- In-space propulsion, Isp>1000 sec
- Power systems, >200 w/kg
- Integrated Human/robotic capabilities
- Crew countermeasures for 100 days
- Closure of water/air systems
- Materials, factor of 9
- IVHM - Integrated vehicle health monitoring
- Current launch systems

Accessible Planetary Surface Capability

- In-space propulsion, Isp>3000 sec
- Power systems, >500 w/kg
- Robotic aggregation/assembly
- Crew countermeasures for 1-3 years
- Complete closure of air/water; options for food
- Materials, factor of 20
- Micro-/Nano- avionics
- ETO @ ~$2000/kg

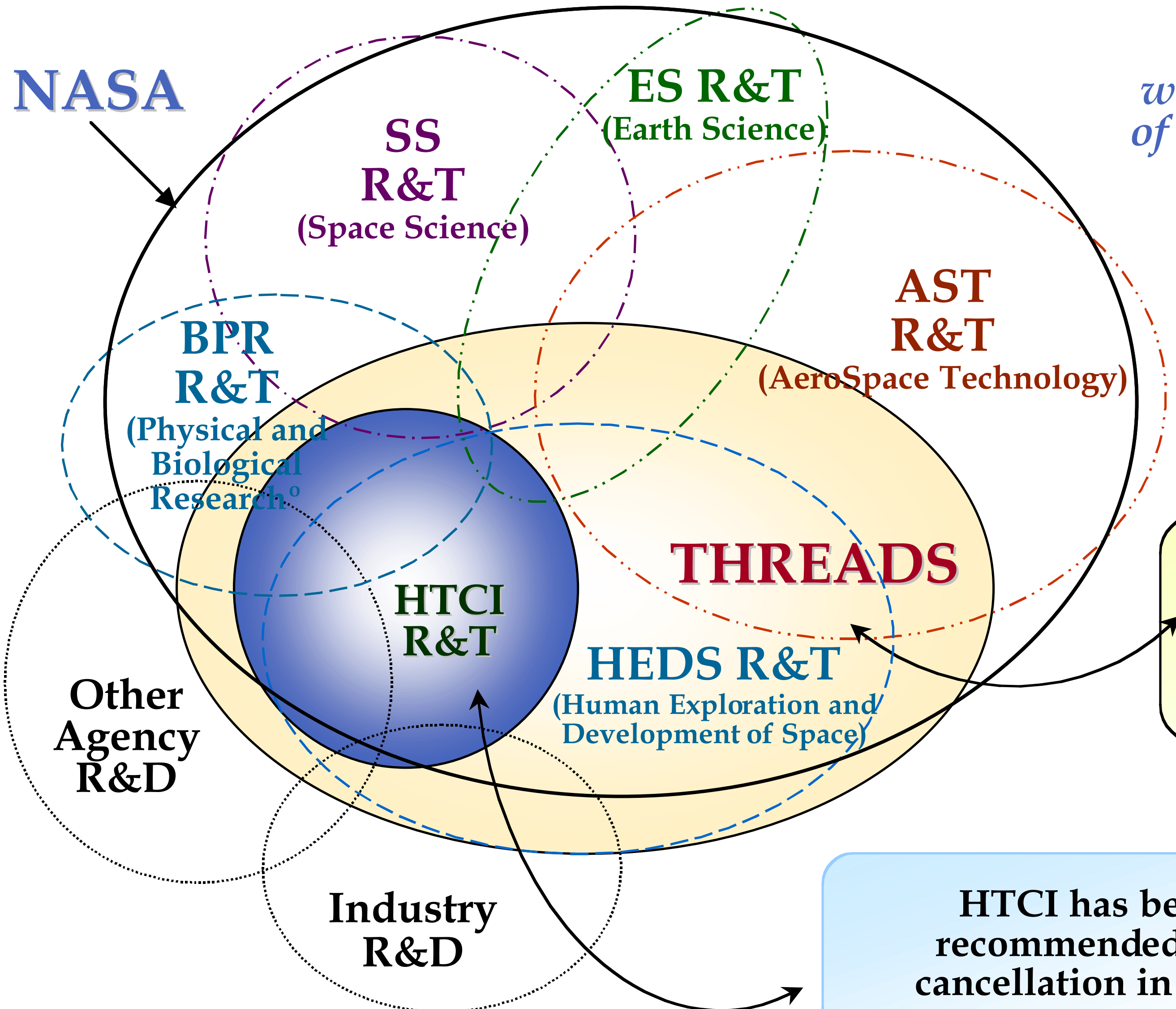
Sustainable Planetary Surface Capability

- In-space propulsion, Isp>3000 sec
- Sustainable power systems
- Intelligent systems, orbital and planetary
- Crew countermeasures for indefinite duration
- Closure of life support, including food
- ISRU for consumables & spares
- Materials, factor of 40
- Automated reasoning and smart sensing
- ETO @ <$2000/kg

Now **2010+** **2020+** **2030+**

THREADS
Agency/Programmatic Context

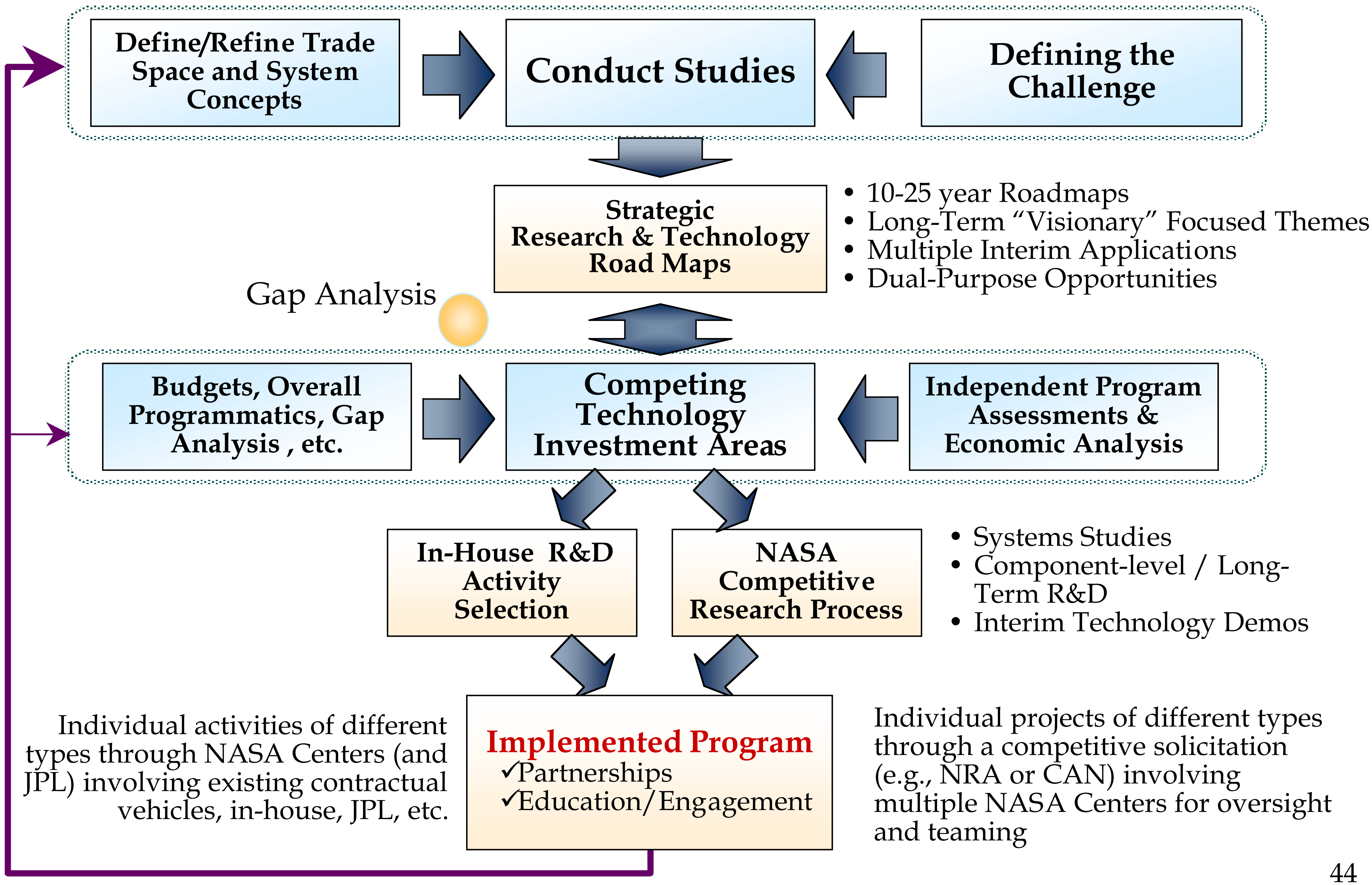
THREADS place within the overall context of NASA's Enterprises and R&T Programs



Technology for Human/Robotic Exploration and Development of Space (THREADS)

HTCI has been recommended for cancellation in FY02

THREADS
Integrated Strategic Technology Process



THREADS

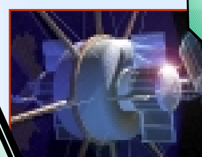
Work Breakdown Structure

- THREADS
  - 1.0 Systems Integration, Analysis, Concepts, Modeling
  - 2.0 Enabling Advanced Research and Technology
    - 2.1 Space Resources Development
    - 2.2 Space Utilities and Power
    - 2.3 Habitation and Bioastronautics
    - 2.4 Space Assembly, Inspection and Maintenance
    - 2.5 Exploration and Expeditions
    - 2.6 Space Transportation
  - 3.0 Technology Flight Demonstrations

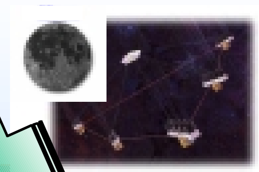
THREADS
2001 Accomplishments - Systems Analysis, Concepts and Modeling

Architecture Studies: Identifying Technology Needs

Technology Needs



Architecture Studies

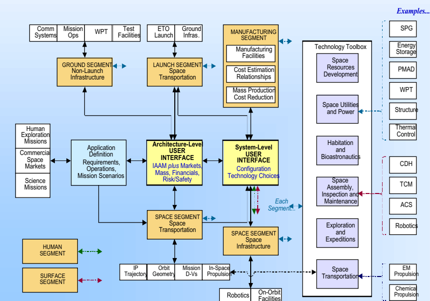


Mission Options

Defined an Architecture for a new, integrated Tool for Technology-Systems Analysis Studies

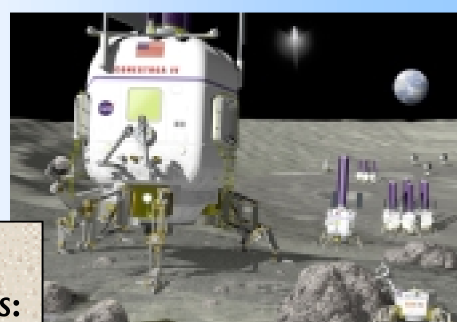
Will enable Technology Assessments and Sensitivity Studies

Systems Analysis Studies: New Tools for Technology Analysis



"TITAN" — THREADS Integrated Technology ANalysis Tool

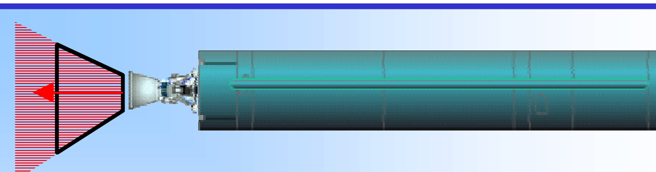
Habitat-Robots ("Hab-Bots")



Advanced Concepts Studies: Defining New Concepts Using New Technologies

Modular Lunar or Mars Surface Exploration Systems

Enables Global Science Scenarios, while establishing a permanent Outpost



Revolutionary ETO Rocket

Revolutionary Materials

After-burning / Hyper-mixing Ejector

Pulse Detonation Wave Rocket Engine

"Launch Assist"

High Energy Density Fuels

Advanced Concepts Studies: Suggesting Revolutionary Concepts Using Revolutionary Advances in Technology

THREADS
2001 Accomplishments - Enabling Research and Technology

2.5 Exploration and Expeditions

Crew-Mobile Distributed Computing and Communication (CDCC)

Houghton Crater testing

Addition of Geology Field Lab prototype for rock sample analysis aboard All Terrain Vehicle

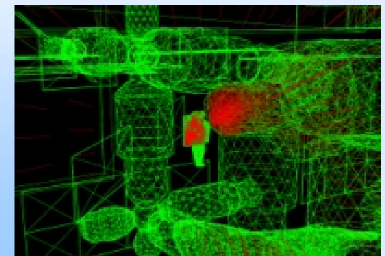
Advanced human-system interaction studies

2.3 Habitation and Bioastronautics

Preliminary US Hab module in ISS

Preliminary Shuttle spacesuit model

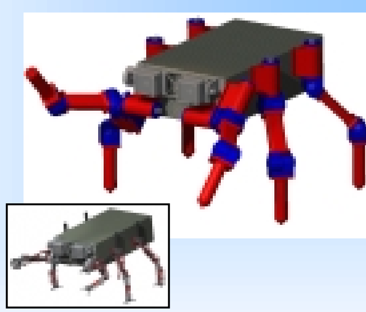
Analysis of 35 MeV proton test at Lawrence Berkeley Lab



Lightweight Radiation Shielding Materials and ISS Operations

2.4 Space Assembly, Maintenance and Servicing

Precision Mobility for Miniaturized Robotic Systems



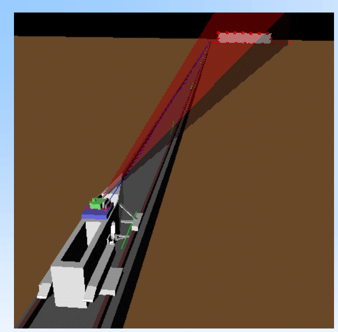
"Hexabot" Robot

New 6-axis force sensor

New High-torque, high-precision, high-accuracy joints

2.6 Space Transportation

Precision Landing and Hazard Avoidance



GNC Requirements Document ver. 1.0

Development of analytic IMU error propagation expression for deduced reckoning

Simulation and processing of China Lake rocket sled data, and development of algorithms for China Lake sled initialization

THREADS
2001 Accomplishments - Technology Demonstrations

3.0 Technology Flight Demonstrations

Coordination with, and Leveraging of Other US Agency Investments

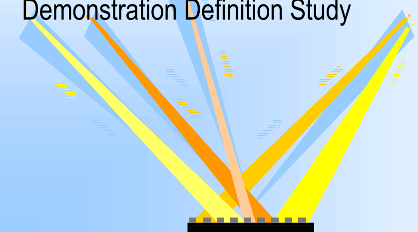
DOD, DOE Others

Advanced Concept Technology Demonstrations (ACTDs)

Opportunities include Space Utilities and Power, Space Assembly, Maintenance, Inspection and Servicing

Example:
2.2 Space Utilities and Power

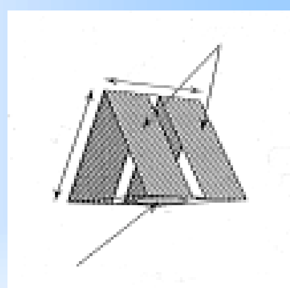
- Multiple-Aperture Laser WPT Expt Definition, using and Concepts for ground and flight demos for laser WPT to efficient PV panels and a Retrodirective beam control system
- Cryogenic Propellant Demo Technology Demonstration Definition Study



3.0 Technology Flight Demonstrations

HTCI Technology Flight Experiments and Demonstrations Definition Studies

Coordination with, and Leveraging of non-US Investments



Example: Japan

Coordination with Japanese SSPS Technology Flight Demonstration Studies

100kW-1MW Class SSPS Demonstration (Phase A Study)

3.0 Technology Flight Demonstrations

Example: Russia

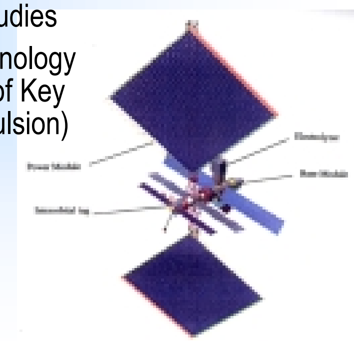
Oversight and US Sponsorship of ISTC Projects

1172: Manned Mars Mission Studies

2120 Manned Mars Mission Technology Development (including Demos of Key Technology -- e.g., Electric Propulsion)

I S T C

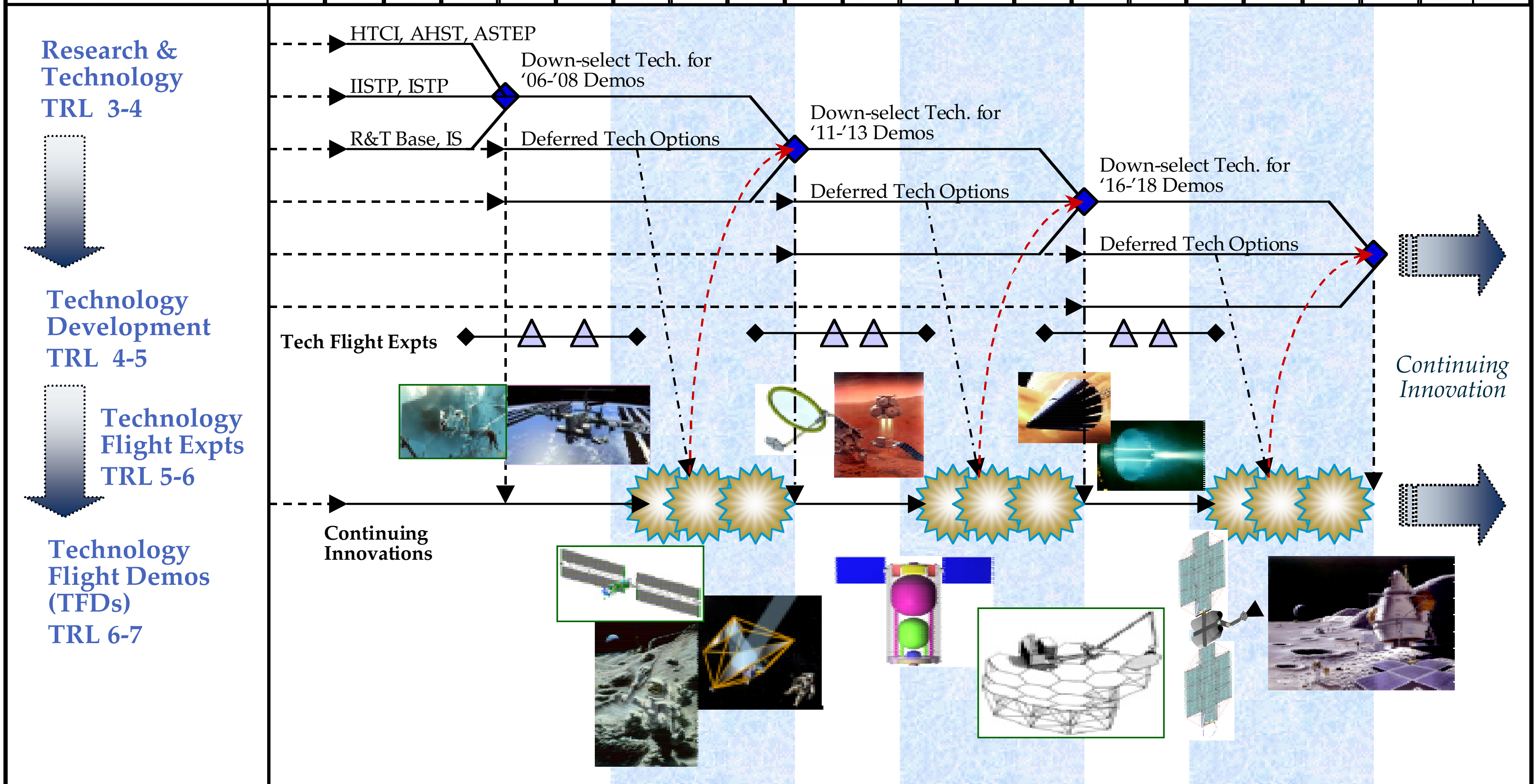
М Н Т Ц



THREADS

Strategic Research and Technology Road Map

	< 2001		2002-2006					2007-2011					2012-2016					2017-2021				
	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21
THREADS '02 ($,M)	N/A	N/A	95	231	329	388	395	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Supporting R&T ($,M)*	<250	<250	~430	~590	~630	~650	~670	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD



LEGEND ◆ Strategic Research and Technology Decision Point △ Major Technology Development Milestone ✷ Major Technology Flight Demonstration

*NOTE: Supporting resources includes other proposed augmentations for FY '02

THREADS
"Top-10" R&D Areas for Investment Attention

"Earth Neighborhood" Mission Driven	Accessible Planetary Mission Driven	Sustained Planetary Presence Driven
√ **Solar Power (High Power)**	√ **Regenerative Life Support Systems**	√ **Advanced Habitation Systems**
√ **Space Assembly, Maintenance & Servicing (Robotic, EVA)**	√ **Surface Science & Mobility**	√ **Nuclear Power**
√ **Cryogenic Propellant Depots**	√ **Materials and Structures** (Manufacturing Validation)	x In Situ Resource Utilization
√ **Biological Risk (Radiation)**	x Space Medicine and Health Care	x In Situ Manufacturing
√ **Aero- Assist/Entry and Landing**	x Earth-to-Orbit Transportation	x Flying Systems
x Electric/Electromagnetic* Propulsion (High Power)	x In-Space Chemical Propulsion	
x Adaptation and Countermeasures (Gravity)	x Nuclear Propulsion	
x Communications and Control		
x Human Factors and Habitability		

The "Top-10" in '03 for THREADS

- √ **Advanced Power (Solar, Nuclear Power)**
- √ **Biological Risk (Radiation)**
- √ **Space Assembly, Maintenance & Servicing (Robotic, EVA)**
- √ **Aero- Braking/Assist/Entry**
- √ **Regenerative Life Support / Habitation Systems**
- √ **Surface Science & Mobility Systems**
- √ **Materials and Structures (Mfg)**
- √ **Cryogenic Propellant Depots**

PLUS…

- √ **Systems Studies, Advanced Concepts, etc.**
- √ **Technology Flight Demos**

** - New Investments Achieved Since Last Year*
√ - New funding required
X - Already funded within agency